RAPID COMMUNICATION

A NOAA Fisheries science perspective on the conditions during and after COVID-19: challenges, observations, and some possible solutions, or why the future is upon us

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Abstract: Many fisheries and marine science organizations are working to determine how to meet their missions in the midst of the COVID-19 outbreak. As such, it seems prudent to exchange ideas, share knowledge, and initiate a discussion among us. As the scientific leadership team for NOAA Fisheries, we wanted to offer some perspectives. Others are also evaluating the impacts of COVID-19 but from the perspective of addressing tactical, day-to-day concerns of restarting operations for various marine and fisheries-oriented organizations. Thus, it seemed appropriate to us to explore the potential challenges posed by COVID-19 and to purposefully ascertain whether there are strategic opportunities for improving how we conduct our operations. We need to find ways to mitigate the effects of COVID-19 on our mission and also to glean information from our responses while in the midst of the crisis. We offer some recommendations to that end and offer these thoughts not as having solved every problem, but to learn from each other, compare across organizations, and engage in dialogue within our discipline to advance much-needed changes.

Résumé : Des organismes des secteurs des pêches et des sciences de la mer s'affairent à déterminer comment s'acquitter de leurs missions en pleine éclosion de COVID-19. Il apparaît ainsi prudent pour ces organismes d'échanger idées et connaissances et de discuter les uns avec les autres. En notre qualité d'équipe de direction scientifique du secteur des pêches de la NOAA, nous souhaitions présenter certaines réflexions. D'autres parties prenantes évaluent aussi les impacts de la COVID-19, mais dans la perspective d'aborder des considérations tactiques et au jour le jour liées au redémarrage des activités pour différents organismes axés sur le secteur marin et les pêches. Il nous semblait donc pertinent d'explorer les défis potentiels que pose la COVID-19 et d'établir s'il existe des perspectives stratégiques d'amélioration de nos activités. Nous devons trouver des moyens d'atténuer les effets de la COVID-19 sur notre mission et de tirer de l'information utile de nos réactions durant cette crise. À cette fin, nous formulons certaines recommandations et les offrons non pas comme solutions à tous les problèmes, mais pour apprendre les uns des autres, établir des comparaisons entre organismes et soutenir le dialogue au sein de notre discipline afin de favoriser la mise en œuvre de changements nécessaires. [Traduit par la Rédaction]

Introduction

Many fisheries and marine science organizations are working to determine how to meet their missions in the midst of the outbreak of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which is causing coronavirus disease 2019 (hereafter COVID-19). As such, it seems prudent to exchange ideas, share knowledge, and foster a discussion among us. Others are also evaluating the impacts of COVID-19 in a marine and fisheries context (Kemp et al. 2020; Bennett et al. 2020), but from the perspective of addressing tactical, day-to-day concerns of restarting operations for various marine and fisheries-oriented organizations (Doremus 2020; FAO 2020*b*). Thus, it seemed appropriate from our vantage point within the NOAA Fisheries' (National Oceanic and Atmospheric Administration National Marine Fisheries Service) science enterprise to explore the potential challenges posed by COVID-19 and to ascertain whether there are strategic opportunities for improving how we conduct our operations — in the spirit of Winston Churchill: "never let a good crisis go to waste". Ultimately, we need to find ways to mitigate the effects of COVID-19 on our mission. We also need to glean information from our responses while in the midst of the crisis to take advantage of lessons learned that could improve how we conduct our mission moving forward (NOAA 2009; NMFS 2019; Doremus 2020).

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The COVID-19 situation is unprecedented, at least in the context of the past 100 years of fisheries science and management. Certainly, there have also been temporary shocks to fisheries systems due to acute pulse events such as hurricanes, oil spills, etc. (McLaughlin 2008). But mostly those have been short-term and highly regional in nature, not impacting the entire national fisheries science and management system. The closest lessons one can learn would likely be from the influenza pandemic from circa 1918 (Reid et al. 2001; Niall et al. 2002; deValpine 2015), but the machinery to manage fisheries was not nearly as established then as it is today. Lessons one can learn from the 1918 situation, acute events, and the current COVID-19 situation include the need to uphold all the human health and epidemiological guidelines while (often creatively) maintaining our ability to monitor, measure, and manage fishes to provide seafood for the nation. The salient point from our current and historical situation is that although what follows focuses on our mission, the health and safety of the many fisheries professionals working at NOAA Fisheries, of our partners, of our stakeholders, and of the communities in which we work remains a priority.

We acknowledge that there are observed drastic changes in global and regional seafood and fishing-for-hire markets (e.g., Doremus 2020; FAO 2020*c*, Kemp et al. 2020; NOAA Fisheries 2020*a*), which have already been recognized as vulnerable to major shocks (Gephart et al. 2016, 2017; Cottrell et al. 2019). For the foreseeable future, at least in the medium-term (i.e., next several years), COVID-19 will impact the market dynamics and associated economies. How that influences the status of stocks that support such markets and the science needed to support these shifts remains a challenge (FAO 2020*a*, 2020*b*; NOAA Fisheries 2020*a*).

To conduct our mission of managing the nation's living marine resources (LMRs), we need to understand the basics of fish, fisheries, special status (e.g., protected resource) species, the habitats that support them, the oceanographic and environmental conditions that affect them, the socioeconomics that impact human choices relating to these species, and the interactions among them, ideally as a composite, integrated system (at least for a given region; Link et al. 2015; NMFS 2016*a*, 2016*b*; Lynch et al. 2018; Peters et al. 2018). To provide mandated management advice for these LMRs and their associated human communities, we need to have meetings, venues, and protocols that use the best scientific advice available and debate the best options within those scientifically determined conditions. To provide scientific advice, context, and conditions, we need to forecast and assess ecosystems, protected resources, habitats, and fished stocks. To execute those forecasts and assessments, we need suitable data. To obtain the requisite data, we need to not only maintain suitable databases, but conduct surveys, sampling, and other forms of information collection. To accomplish all of the preceding, we need professional and well-trained personnel.

The situation in 2020, and perhaps well into 2021, is that it will be the year(s) with severely limited data collection. Though some operations are underway, including limited small-scale regional NOAA Fisheries field work and NOAA vessel operations, these have been limited and are operating under notable health and safety restrictions. In fact, we have already had to cancel most of our major cruises and surveys in 2020 (Doremus 2020; The Maritime Executive 2020*a*, 2020*b*; NOAA Fisheries 2020*b*, 2020*c*); as of this writing, we have cancelled over 50 fisheries surveys resulting in a loss of over 1500 on-the-water days-at-sea. So that begs the question, how do we obtain our necessary data under these conditions? More so, how do we conduct our analytic efforts to assess the LMRs we are mandated to manage? Finally, how do we evaluate and communicate the increased uncertainty that will result from any unrecoverable data gaps?

The situation is also one without in-person meetings and with highly constrained travel (Viglione 2020). This limits the exchange of scientific information and also limits the ability for scientists, managers, and stakeholders to meet and discuss issues related to marine resource management. Most of these meetings have moved to virtual formats. For example, the American Fisheries Society Annual meeting was held virtually in 2020, whereas the Annual Science Conference of the International Council for the Exploration of the Seas has been postponed to 2021. The release of the Food and Agriculture Organization (FAO) State of the World's Fisheries and Aquaculture report was similarly broadcast virutally world-wide in over four languages. A number of smaller scientific meetings are successfully moving to virtual formats. Management-related meetings are also being held virtually. In the US, regional Fishery Management Councils and Status Review Groups meet three to six times per year to manage marine fishery resources, let alone any subcommittee work. Since March 2020, all of these Council and Status Review Group meetings have been held virtually, along with the attendant committee meetings and public comment events.

The impacts from COVID-19 will have different magnitudes. For example, we all can probably recover some functionality via virtual meetings and as travel restrictions begin to lift, but loss of data, disrupted time series, etc., are considerable with the inability to ever collect the data missed in 2020. The cost of that data gap will diminish over time, and although modeling or imputation methods may be successfully employed to fill in and provide usable time series of data, the actual data gaps can never be filled. The impacts from COVID-19 also vary in time. There are relatively short-term (approximately next 6 months) and long-term (3–10 years) consequences of the impacts from COVID-19. At NOAA Fisheries, we have long recognized the need to move beyond the normal, "bread and butter" assessment approaches into next-generation assessments and forecasts and also to begin to adopt more efficient and advanced sampling technologies (e.g., Lynch et al. 2018), but we have not always had as clear and urgent of a driver to force such a change. We have also recognized that the ever-increasing number of in-person meetings comes at a cost in terms of time, money, and the environment. It could be that the COVID-19 situation is a driver of such changes that we have long considered and that are still needed.

As the scientific leadership team for NOAA Fisheries, we wanted to offer some perspectives to the fisheries and marine science community on these topics in the midst of COVID-19. What follows are some thoughts to help mitigate the current circumstance that could also have bearing on future ways we conduct our mission. Although this work focuses on responses to COVID-19, it could be that any lessons learned also have application for other, future "shocks" to the fishery system in the US or elsewhere. We aim to identify issues related to data, analysis, and meeting as they are affected by COVID-19 and propose some suggestions of how we might address those challenges. We offer these thoughts not as having solved every problem, but to learn from each other, to compare across fishery and marine science organizations, and to engage in an active dialogue within our discipline to advance much-needed changes.

Data collection in the context of COVID-19

The basic data needed to assess our LMRs are well-documented (Ballance et al. 2017; Lynch et al. 2018) and are not repeated here. To assess habitats and ecosystems may require additional data (NMFS 2016*b*; Peters et al. 2018), but often those analytical efforts involve using the same basal data as in stock or protected resource assessments, with rearrangement of how the data are treated (Samhouri et al. 2010; Shin et al. 2010; Fay et al. 2013, 2015; Large et al. 2015; Slater et al. 2017; Libralato et al. 2019). Here we address the case of increasing loss of data collection capability due to COVID-19.

Maritime operations and associated logistics are challenging enough under routine circumstances, let alone in a pandemic with added layers of health and safety considerations. Not only are there at-sea operations, but there is also a substantial amount of shore-based preparatory work before a ship's departure (e.g., staging, instrument calibration, net repairs, loading of supplies) by personnel, whose access to facilities and laboratories is restricted given enhanced health and safety protocols. Hopefully, operations can resume safely, with sufficient COVID-19 mitigation protocols, sooner than later. Some University–National Oceanographic Laboratory System vessels have recently begun research cruises (Graber-Stiehl 2020), and other oceanographic efforts have begun to be reinstituted (Berwyn 2020; Heslop et al. 2020), as has a limited number of our cruises. We also note that fishing activities have continued. There is a large array of risk factors for which there remain no simple solutions for marine operation considerations (Addetia et al. 2020). Realistically 2020 (and likely beyond) will be a year with major data gaps, and we will need to adjust our analytical efforts accordingly. Furthermore, although there is considerable effort to restart data collection programs now and into 2021, it is unclear when the full suite of data collection programs will be back on-line. We recognize the dedication of our survey groups around the country and their commitment to obtaining fisheries-independent data. We also want to deftly manage the expectations for realistic data collection in the context of COVID-19-related risks.

Most of our fisheries–LMR data are presently collected via fishery-independent surveys that are mainly conducted on vessels that are either part of NOAA's fleet or are commercially chartered. Halting data collection during the COVID-19 situation resulted in large part from our dependence on these vessels as our principal data collection platforms, which in turn depend on at-sea deployment of personnel for their operation. Similar data collection stoppages in the future can be lessened through diversification of sampling approaches, which in addition to offsetting the risk of data loss, can increase the quantity and breadth of our data and information collection. Recognizing that diversified and increased data collection will also require parallel efforts in calibration, data storage, and analysis, we suggest possibilities below for replacing or augmenting our traditional data collection platforms during COVID-19 and beyond.

Assuming that challenges to conducting fishery-independent surveys and collection of associated data, marine mammal abundance surveys, and similar sampling efforts will persist, or that those surveys will be severely compromised for 2020 and potentially into the future, it seems prudent to emphasize platforms of opportunity and sampling of catches — fisheries-dependent data — when and where we can do so safely. We acknowledge that fisheries-dependent data are also affected by COVID-19-related restrictions on data collection (i.e., sea sampling, at-sea observation, port sampling, and recreational fishery angler intercept sampling have all been curtailed by disruptions). We also acknowledge that commercial and recreational fishery monitoring are differentially affected. However, fisheries are operating, and people are returning to work and providing food for the nation. Thus, the next steps in the effort to obtain such information might wisely be focused on dealers, processers, and captains or leaders of fishing consortia at key ports. Admittedly, deploying fisheries observers (NMFS 2020*a*, 2020*d*; Kearns 2020) has presented major challenges in the context of balancing data collection with health and safety concerns (NMFS 2020*d*; NOAA Fisheries 2020*e*). Certainly, there are concerns of bycatch, misreporting, under-reporting, and how one ultimately considers observers, electronic monitoring, or other forms of independent verification of these fisheries-dependent data (Ames et al. 2007; van Helmond et al. 2020). Intercept sampling of recreational anglers will also continue to be limited for the foreseeable future; however, off-site mail, telephone, and internet surveys are still able to continue to collect these recreational trip and effort data. What we are proposing is that this sampling emphasis would be primarily executed by port agents to double-check and work with the reporters of landings (e.g., dealers, processors, association leaders), using extant methods to ascertain the degree of catches that we already have reported to us while following COVID-19 guidelines (e.g., social distancing, masks). Providing these total catch or even total landings data would afford us the opportunity to at least employ "catch-only" or catch and primary production methods (noted below) and would allow us to project some assessments forward with these data inputs.

Other important fisheries-dependent data include social and economic data. We acknowledge drastic changes in global and regional seafood and fishing-for-hire markets (e.g., Doremus 2020; FAO 2020*c*; Kemp et al. 2020; NOAA Fisheries 2020*a*), and the need to track these facets of fisheries remains important to ascertain the impacts of fisheries advice, fisheries management decisions, and COVID-19 effects. Much of the same efforts noted above — focused on dealers, processers and captains or leaders of fishing consortia at key ports, as well as recreational fishing surveys — can also be used to obtain necessary social and economic data.

NOAA Fisheries' Cooperative Research Program (NMFS 2020*f*) is another approach to how we collect either primary or auxiliary data to help fill information gaps that are currently missing or limited. This program already works with many partners to collect a range of environmental and fisheries-relevant data; for example, temperature measurements on lobster traps. There may be a possibility to expand cooperative research with commercial fishers in an attempt to do survey sampling for us in lieu of their normal fishing operations. This can provide information from many missing components of the survey and offset economic loss from the fishery due to COVID-19. Similar to the loss of large amounts of fishery-independent data in 2020, our collection of ecosystem-level data are lacking in a year where many ecosystem changes are occurring. These cooperative programs may also be of added value in collecting these ecosystem data, as well as advancing the research, development, and operationalization of new sampling technologies. There are numerous cooperative data collection efforts across the country, and these could be augmented where possible to support filling these knowledge gaps. Similar to the analytical considerations noted below, cooperative efforts take time; perhaps the COVID-19 situation provides further impetus for diversifying data collection among these efforts (NRC 1998).

Crowd-sourcing of suitably validated data (e.g., "citizen science"; Fairclough et al. 2014; McKinley et al. 2017) remains an option to collect necessary data (Fairclough et al. 2014; NOAA Science Advisory Board 2018). The current situation provides an excellent opportunity to further consider other forms of citizen science, such as further developing the use self-reporting (Mangi et al. 2015; Jiorle et al. 2016; NOAA Fisheries Office of Science and Technology 2020), electronic reporting and monitoring methods (Jiorle et al. 2016; NOAA Fisheries Office of Science and Technology 2018*a*, 2020), and internet search volume (Carter et al. 2015). These approaches may be particularly appropriate for recreational fisheries (Jiorle et al. 2016; Venturelli et al. 2017; Crandall et al. 2018). We acknowledge that there are challenges associated with citizen science data collection, especially self-reporting (e.g., levels of opting-in, validation, statistical design, data standards, etc.; Venturelli et al. 2017; Crandall et al. 2018). Certainly compliance in reporting and accuracy of information would remain concerns, but ensuring adequacy of information could be tied directly to the decreasing of buffers for setting annual catch limits noted below (i.e., leading to increases in catch), and doing so would incentivize the industry and nongovernmental organizations (NGOs) to self-report, self-police, and provide an impetus for us to update our database capabilities (Ames et al. 2007; Kindt-Larsen et al. 2011; Hold et al. 2015). Escalating some form of electronic or related monitoring seems appropriate in the COVID-19 situation (Kindt-Larsen et al. 2011; CCFA 2020; Gibson and Wozniak 2020; SFP 2020).

To efficiently and reliably collect necessary data, developing and beginning to more widely use enhanced forms of passive monitoring seems appropriate. The present situation (and moving forward with budget constraints, an aging fleet, and associated challenges to reliability) reinforces such a need. For instance, some satellite-based examples are noted in the section below. Other satellite applications could be the expanded use of vessel monitoring systems (VMS; Witt and Godley 2007). From VMS, one can determine whether a vessel is exhibiting fishing behavior (e.g., changes in velocity). From fishing behavior, one can estimate fishing effort (Watson 2017; Watson et al. 2018). From fishing effort, one can estimate fisheries catch (Bastardie et al. 2010; Watson et al. 2013). From catch, one can estimate landings and use associated analytical methods (Bastardie et al. 2010; Gerritsen and Lordan 2011; Watson 2017). Such estimates might be relatively imprecise estimates, but could be an improvement over no estimates at all. Certainly not every vessel nor every fleet is equipped or required to have VMS, but this would provide a way to get at least a minimum estimate of catches. Plus, most commercial and many recreational vessels have some form of satellite positioning system that could be readily adjusted to VMS needs. Many of these are trackable via web-based applications. Working in partnership with the NOAA Fisheries Office of Law Enforcement, we have the theoretical capability to at least count fishing vessels, and those vessel counts could be used as a proxy for fishing effort as noted above.

Passive acoustics (e.g., set or moored arrays, towed transducers) are in place for many, but certainly not all, regions or species (van Parijs et al. 2009; Heupel and Webber 2012). These can be better utilized to target key taxa, both fished and protected resource species, to obtain indices of relative abundance. There are nuances to this approach, including whether acoustic signatures to identify taxa of interest exist, if the extent of an array covers a reasonable fraction of the taxa's distribution, the timing of major migration events of certain taxa, and even whether some taxa have been acoustically tagged to ground-truth the array. Yet given those limitations, it may be that these arrays provide a short-term solution; recalibrating and using extant arrays might allow us to get such estimates of relative abundance relatively quickly, particularly if staff are not able to be widely deployed on manned platforms.

Similarly, there are many novel, promising, and innovative technologies to sample and survey LMRs (Bradley et al. 2019; Moustahfid et al. 2020; NOAA 2020). Unfortunately, some are not yet at the level of technological development (e.g., eDNA, 'omics) ready for use in surveying LMRs to the scope and extent that is needed, and some of them are quite labor- and fieldwork-intensive. Yet despite the intensity of labor, some of those possibilities may provide helpful options relative to the alternative. This is particularly true for technologies (e.g., hexacopters, drones) that focus their sampling on land or surface-based organisms, such as many marine mammals (e.g., Torres et al. 2018). Saildrones, autonomous underwater vehicles, and related, self-contained samplers have acoustic, visual, and oceanographic sensor capabilities that are underutilized as data streams for our data needs (Harris et al. 2019; Moustahfid et al. 2020). The technology exists to make these "force-multipliers" for our normal, manned surveys. In some instances (Antarctic, sub-Arctic, and Arctic), these technologies are already used to partially survey given regions. We could redeploy drones and autonomous underwater vehicles in the present situation (albeit in a limited sense) and plan to scale up such efforts for future years, making this a clear area for escalation (NOAA 2020); we are already deploying gliders in the Antarctic peninsula and saildrones in the Bering Sea for this purpose (NMFS 2020*e*). The degree of sampling coverage and breadth of information will be less than we would have in a normal year, but would be more than if not deployed. Certainly, cross-validation and cross-calibration studies would be necessary (NOAA 2020), but those could be done post hoc after data from these technologies were captured.

While we recommend focusing on catch data to mitigate the immediate impacts of COVID-19, we also need to acknowledge the need for data collection that supports ecosystem indicators, which can provide environmental context to expectations for recruitment, vital rates, and distribution (Slater et al. 2017; IEA 2019; Dorn and Zador 2020). These data can be collected via many of the crowd-sourcing, cooperative research and similar partner-based efforts noted above. The important point is the acknowledgement that contextual information is needed for any fishery-dependent data collected, and the ability to do so is likely more feasible than is typically expected.

Moving forward, we need to continue to evaluate all of our sampling and survey options, but likely with more urgency and a sharpened sense of how exceptional circumstances can impact our mission. Focusing on catch data and the new electronic means to obtain that information seems quite feasible and even more necessary in this COVID-19 situation (Table 1). Some of these recommendations urgently need to be addressed (e.g., managing expectations, redeploying advanced technologies, port-based sampling, better utilizing crowd-sourced data); some need to be started now and continued into the future (e.g., better use of vessel monitoring system data, better use of passive acoustics); and some need to perhaps be used to improve our long-term operations (Table 1). The present situation has also highlighted our vulnerabilities with respect to being too dependent on any one type of platform and its related data streams. The role of additional study fleets, charters, and other platforms for hire would be wise to more fully explore, as would be how to escalate the rate of adopting advanced sampling technologies in an operational sense (NRC 2011; NOAA 2016).

We recognize that adding new data series and collection methods to assessments is not "turn-key". There is substantial effort needed for calibration, development and management of data systems, and incorporation into assessments (Ballance et al. 2017; Lynch et al. 2018). LMR management is largely supported by time series, so that status and trends of the resources can be evaluated. New data types without calibration have little long-term perspective, and thus their immediate value is limited, but can be built over time. Also, the addition of new data to assessments generally involves peer review; new data collection approaches need to be synced with assessment review processes. That said, we knew we would benefit from additional fishery-independent options even prior to the present situation (NMFS 2020*b*), but the COVID-19 situation is effectively forcing the reevaluation and adaptation of our data collection methods, as well as the associated urgencies to do so.

Analysis, forecasts, and assessments in a limited information context

NOAA Fisheries assesses a wide range of fish stocks, protected resources, habitats, and ecosystems, but impacts to data collection will degrade the precision of their results and pose challenges for their execution. Capabilities and methods are already in place for situations that are or become data-poor (e.g., Cope and Punt 2009; Carruthers et al. 2014; Chrysafi and Kuparinen 2016; Geromont and Butterworth 2015), even for full ecosystem assessments (Smythe and Thompson 2015; dePiper et al. 2017; Francis et al. 2018; Reum et al. 2020). While we conduct our assessments regularly, we do not do all assessments every year. To ensure that the most important needs are met first, we have established a system for prioritizing our assessment work, which not only identifies where assessments are needed most, but also supports decisions about when more streamlined "operational assessments" can be used versus more resource-intensive "full assessments" (Methot et al. 2014; Lynch et al. 2018). Our ability to be more efficient is supported by our robust databases and increased understanding of system and species' dynamics, and our need to be more efficient is largely driven by rising

Table 1. Summary of key recommendations for core science aspects of the NOAA Fisheries mission.

Analysis, forecasts, and assessments
With available, mostly up-to-date data
Continue with short-term projections for stocks assessed with a dynamic method
Employ data-poor methods for stocks with appropriate data
If limited or dated data
Escalate establishment of management strategy evaluations, ideally for groups of species
Establish or adopt predetermined management procedures
Explore scenario planning
Use indicator methods and statistically project forward
Adopt satellite-based indicators to project total catches
Adopt early warning signals (satellite-based) using environmental condition indicators
Use extant risk assessment and vulnerability analyses to triage what can reasonably be left alone and what needs urgent attention
In absence of any new information, defaults should:
Retain continuity (last year's annual catch limit, potential biological removal)
If information suggests otherwise, then adopt a precautionary approach
Data collection
General considerations and focus
Manage expectations of our surveying capacity
Maintain port-based and use reporting individuals for catch data
Revisit cooperative research emphases
Establish crowd-sourced data sources and infrastructure to support them
Escalate adoption of electronic monitoring
Passive monitoring
Expand and better use vessel monitoring system data to estimate effort and catch
Expand and better use passive acoustic arrays
Advanced sampling technologies
Redeploy and use extant drones, hexacopters, and autonomous underwater vehicles
Escalate broader adoption of advanced sampling technologies
Advice and debate with no travel
Continually evaluate travel criteria approval
Evaluate effectiveness of online and in-person meetings, with standards for appropriateness of each
Assess online meeting strengths and weaknesses, with suggested protocols and guidelines
Invest in information technology hardware and software for online meeting
Evaluate effectiveness of telework and work-from-home protocols

costs and shrinking days-at-sea (Punt et al. 2020; ICES 2020; NOAA Fisheries 2020*d*). Thus, we do have protocols in place to scale our assessment efforts as needed.

In the COVID-19 situation, we acknowledge that missing data will make stock, protected resource, habitat, and ecosystem assessments more imprecise and potentially even cause assessment methods to fail. With that being the case, we should strive to identify and account for any uncertainty that such missing data causes and address that as consistently as possible among stocks, protected resources, and ecosystems. However, the big question is that if there are no data available to update assessments, even where data-poor methods are used, do we still have options to meet our assessment and advice-providing needs? The answer is that we do; much of our current enterprise has some built-in robustness to these circumstances, at least for the near term, and in other situations, we have an opportunity for creativity and advanced technical and interdisciplinary solutions. What is proposed here is presented for the case when the ability to collect the requisite information is compromised (cf. ICES 2020), with notations on options at different points in time.

The first and most obvious option is, for stocks assessed with dynamic methods that allow forecasting (Lynch et al. 2018), to simply project the stock forward an additional year with a range of assumptions about stock conditions and catches during 2020 and 2021. In fact, the impetus for this work is largely driven by the reality that there will be instances where some or all of the requisite data are missing for this time period. Using forward projection methods without updated data would increase uncertainty in management advice but would be little different than the current advice framework (NMFS 2020*c*; Punt et al. 2020) that is routinely based on projections one to several years beyond the terminal year of data in assessment models. As predictions advance further in time, the uncertainty increases, and in some cases, this is reflected in more precautionary advice, though substantial underages in catch could lead to increases in future catch advice when a stock is assessed again in the future with new data. Thus, projections of stock status can be done for a future year with suitable caveats about the uncertainty of the projections absent updated data for this current year. Particularly in these situations where standard fisheries data collection frameworks may be impaired (cf. ICES 2020), socioeconomic data such as fuel receipts, license sales, or social media could be useful to characterize key assumptions (such as the magnitude of recreational catch in instances with limited recreational catch surveys) during this COVID-19 time period.

The second option involves "operational" or update assessments that re-estimate model parameters with additional but sparse data. Thus, there are instances where updating the assessments with only some missing data are a possibility. Most modern, simulation-based assessment modeling approaches (Methot 2009; Geromont and Butterworth 2015; Punt et al. 2016) are designed to handle a certain degree of missing data. Even in cases with very little new data, but for stocks whose assessments have been "skipped" within a tolerable range of frequency (e.g., scheduled for this year, or not assessed within 1–3 years), this approach would still work and could improve upon strictly updating projections. Though, as one is essentially trading data for assumptions, a full accounting of the increased uncertainty may require a broader range of sensitivity analyses to determine the robustness of the modeling framework to missing data. This all collectively implies that there remains some source of reliable data (e.g., fishery-dependent data collected by industry partners; i.e., catch) to use in the update and to mitigate the data loss or else recognizing and clearly communicating that the uncertainty will notably increase with each successive year of our forecasts.

The next assessment options are data-poor methods, which have been used when dynamic stock assessment (i.e., data-rich) methods are unable to be employed (Pitcher 1999; Pitcher and Preikshot 2001; Cope and Punt 2009; Carruthers et al. 2014; Chrysafi and Kuparinen 2016; Geromont and Butterworth 2015). Often, such data-poor methods may be less impacted by loss of data and may continue, provided that some form of reliable indicator exists (such as a fisheries-independent survey; Shertzer and Williams 2008; Ault et al. 2018; Huynh et al. 2020). The modularity of many modern assessment models (Punt et al. 2020) is particularly valuable in this context, where the same platform can serve as a modeling continuum from data-rich to data-poor (Cope 2013), thereby allowing for at least a minimal assessment if data streams erode into the future. To be clear, we are not suggesting that dynamic stock assessment methods should revert to data-poor methods, but the latter does give options for at least a minimal assessment if data streams continue to erode into the future. Any such changes would be multiple years from now, and where possible we recommend retaining the projection methods noted above. We note that many data-poor methods are catch-only approaches and typically rely upon the assumption that a stock was in quasi-equilibrium when the method was applied. This gives a snapshot of advice, but is not intended to be updated with the same equilibrium assumptions. At this point in time, catch data are most certainly influenced by market conditions (Eliasen et al. 2014; Scheld and Anderson 2014), and we understand they are not ideal methods, so would similarly not recommend them unless there are absolutely no other options. That said, this should be an impetus to obtain and use fishery-dependent data beyond just catch (e.g., catch per unit effort (CPUE), albeit with the caveat that fishing behavior has again almost certainly also been affected, thereby impacting the proportionality of CPUE).

Thus, in many instances, methods exist that can be employed this year for fisheries stock and protected resource assessments having limited data; but those would be for instances that have mostly up-to-date data or for stocks that were scheduled for analysis after having not been assessed within a recent time period (e.g., a year or two or some reasonable fraction of the taxa's lifespan). For these circumstances, one would need to manage expectations on the limitations of the data and identify ahead of time the stocks where catch data are not viable. The age structure of longer-lived species gives inertia to those populations such that a data gap is bridged more easily. Where single or multiple year gaps pose a much more acute challenge is for annual and shorter-lived species like shrimp, salmon, and small pelagic species, where catch advice comes almost entirely from very recent information. Here is where creativity and scientific innovations outlined below may provide opportunities. These shorter-lived taxa represent situations where fishery-dependent CPUE could particularly play a role.

One strategic tool in widespread application is management strategy evaluations (MSEs; Smith 1994; Punt et al. 2016), developed to find management approaches that are robust to a range of dynamics and uncertainty and that meet multiple, often competing, management objectives. Various MSE approaches have simulated a range of stock, protected resources, and ecosystem statuses based on a range of harvest control rule options, possible sampling, ecosystem conditions, and other, testable assumptions — all relative to some specified management objectives, with the key point that there are feedbacks in MSEs to elucidate the response of the system to various interventions. While they may have utility here for some provision of tactical advice (e.g., next year's total allowable catch) and certainly are useful in evaluating the value of information such as allocation of survey resources, their primary role is in strategic decision making. We see them playing a greater role for decision making under what is likely to be greater environmental uncertainty and even more explicit consideration of multiple objectives for ecosystem-based fisheries management, as multiple, conflicting objectives and changing ocean conditions have not gone away during COVID-19. However, their most effective utility now is in considering the insights to be gleaned from information gaps, especially via using existing MSEs. For example, how often did the loss of a single year of data immediately trigger an "exceptional circumstances provision", which would result in notably different management advice? Or are management procedures robust to missing data? Or, for ecosystem MSEs, how do broad ecosystem indicators perform and inform as tactical advice? All these situations are commonly explored in MSE evaluations. In most cases, MSEs explicitly consider these situations, and most management protocols build in robustness by averaging several data points so that they are inherently designed to avoid common failure points. Perhaps the COVID-19 situation provides an opportunity to expedite ongoing or new MSEs in more of a "crisis management" mode where the rudiments of MSEs already exist. At the least, the COVID-19 situation highlights the need to escalate the development of MSEs for broader use and provides critical context to evaluate the robustness of our status quo approaches to exceptional circumstances.

In certain cases, management procedures (MPs; de la Mare 1998; Geromont and Butterworth 2015; Huynh et al. 2020; sensu Punt et al. 2016) essentially recommend no change if forecasts of fisheries stocks, protected resources, or projected catches do not fall outside of predetermined levels (often as tested and established via prior MSEs). Some of these "non-benchmark" approaches exist now, but these would not be that difficult to establish for many stocks occurring in stable situations. This would probably work for most stocks where presumably overfishing is thought to have stopped. These are related to some of the dynamic stock assessment projection methods noted above, and certainly they can use MSEs as the quantitative engine, but what distinguishes MPs here in the more generic sense is that they provide a reasonable course of action for acceptable levels of management options. Therefore, short of formal MSEs or related quantitative analyses, for most stocks and taxa that had previous evidence for a stable or increasing abundance and are known to not be overfished or threatened, keeping catch or removals constant at the last annual catch limit level should typically work. Thus, in instances where there are data gaps of at least a year, but with stocks or protected resource taxa in previously known positive conditions, and with no known major changes in parameters that impact the ecosystem and taxa of interest, we could make the recommendation of using the prior year's annual catch limits or potential biological removals; we amplify on this further below.

The challenge is for stocks, protected resources, habitats, or ecosystems where there are limited to no data to update even data-poor methods. There exist other options that could be used in such situations. Scenario planning is a structured, expert-driven process that embraces uncertainty and explores plausible alternative future conditions under different assumptions to help manage risk and prioritize actions (Schwartz 1996; Peterson et al. 2003). It can be thought of as a qualitative MSE. NOAA Fisheries is beginning to use the method to evaluate science and management actions under climate change (e.g., Atlantic salmon, *Salmo salar*; Borggaard et al. 2019). The approach could be used to evaluate any number of actions under shorter-term scenarios, including operating conditions improving or worsening in 2021 or more or less data available in 2021, all in the COVID-19 context. There are comparable, extant, qualitative tools (e.g., conceptual modeling, qualitative network analysis, mental models; Smythe and Thompson 2015; dePiper et al. 2017; Francis et al. 2018; Reum et al. 2020) that can similarly be used for full ecosystem assessments, with particular consideration of the potential ramifications of various trade-offs during COVID-19 conditions.

There are similarly some indicator-based approaches that can be projected for overall system status, status of stocks, protected resource status, and even habitat status (Link et al. 2002; Link 2005; Potts 2006; Samhouri et al. 2010; Shin et al. 2010; Kaplan and Leonard 2012; Fay et al. 2013, 2015; Large et al. 2015; Lederhouse and Link 2016; Fulton et al. 2019; Libralato et al. 2019; Link and Watson 2019). The value of these approaches is that they are often simple and intuitive, and though they benefit from data updates like any other method, they can be extended to 2- to 3-year projections using relatively simple and straightforward statistical methods (Link et al. 2002; Link 2005; Shin et al. 2010; Fay et al. 2015; Probst et al. 2013; McDonald et al. 2017). Some of these indicator approaches are based on catch and primary production for an entire system (Cury et al. 2005; Libralato et al. 2019; Link and Watson 2019). These indicators rely on satellite imagery to obtain primary production (the base of the food web that can support fishes and protected resources; Smyth et al. 2005; Link and Watson 2019) and can be reverse-engineered to estimate how much total catch can be prosecuted in any given ecosystem based on empirical, tested, and theoretically determined limits (Link et al. 2002; Fay et al. 2013; Link and Watson 2019). Allocation projections based on recent precedents are then doable. Certainly, there are nuances of estimating primary production from satellite imagery, as in any of the modeling and assessments we conduct, but this approach provides a means of evaluating our LMR with a series of continuous data. This approach presumes that data streams from satellites will still be available and will not be directly impacted by COVID-19 for the foreseeable future.

Satellite information can also help track major oceanographic features, which once processed into indicators can be used as early warning signals that environmental conditions are changing, thereby adjusting annual catch limits, potential biological removals, or harvest control rules based upon short-term projections of what would likely be substantially altered environmental conditions. We do this in some regions already using our Ecosystem Status Reports as briefed to our Fisheries Management Councils and other partners (e.g., Slater 2017; IEA 2019; Dorn and Zador 2020), and the approach can be readily expanded elsewhere with widely available and remotely sensed, updated information.

Risk assessments and evaluations are perhaps under-utilized methods to frame the status of LMRs. NOAA Fisheries has pushed to have many of these done with respect to climate (NOAA Fisheries Climate Science Strategy; Link et al. 2015), and these climate vulnerability analyses are extant for every region (e.g., Crozier et al. 2019; Gaichas et al. 2014; Hare et al. 2016; Spencer et al. 2019; NOAA Fisheries Office of Science and Technology 2019). They are based on repeatable and intuitive methods, can be based on limited information, and can provide important context of what should be prioritized analytically with respect to this risk. There are also productivity–susceptibility analyses (Patrick et al. 2009) extant for most of the managed fish stocks we report on and that can be used to prioritize analytical efforts. These climate vulnerability analyses and related information can be modified to include other factors, and the productivity–susceptibility analyses can be updated for the ones completed ~10 years ago (Patrick et al. 2009). Some of our Fisheries Management Councils have conducted related exercises, often using the climate vulnerability analysis results or methods (e.g., Gaichas et al. 2018). The value of these analyses is to not only triage assessment and analytical efforts, but to communicate to all interested parties our rationale for why we are not conducting assessments for some stocks, protected resources, habitats, etc., for the immediate future, largely due to the (lower and differential) level of risk. Although indicators, satellites, and risk assessments offer methods to provide management advice, in many instances these approaches are currently not widely used, so similar to the broader use of MSEs, the COVID-19 situation provides an opportunity to expedite these alternative approaches in a "crisis management" mode.

The advice we provide with respect to potential biological removals, annual catch limits, habitat restoration, ecosystem overfishing, etc., can be considered as defaulting to two guiding principles. The first is to retain continuity with preceding years. This approach was reinforced when discussing hurricane forecasts with our counterpart physical modelers (NEMoW3; Townsend et al. 2014); the hurricane modelers have business rules that do not allow them to alter projected hurricane tracks beyond a certain range between forecasts, even if the models, data, and information suggest otherwise (NRC 2006; Meuel, et al. 2012; J. Beven, personal communication). Here we would aim to maintain continuity due to the lack of new information. We need to consider such an approach to mitigate the present situation and in moving forward. This continuity approach is in some respects a type of MP as noted above and is also a precautionary tactic in a general sense. Yet the effective loss of fisheries-independent data, and less-certain fisheries-dependent data, may result in the need for even more precautionary management. This leads to the need for more formal precautionary approaches. Thus, the second option is the sensu strictu application of the precautionary approach to fisheries management (Darcy and Matlock 1999; Essington 2001; Hilborn et al. 2001), which is adopted by most Fishery Management Councils, and is a global best practice for LMR management (Darcy and Matlock 1999; Rosenberg 2002; Punt 2008; Rice 2009). The precautionary approach adds buffers to catch advice (hence catch tends to decrease) with increasing scientific and management uncertainty, or known adverse conditions, all of which increase in the absence of data on the stock or the fishery.

We propose a default for many US fisheries that would maintain catches at or around the previously set level, unless otherwise indicated. If conditions arise that warrant it, or are even suspected, managers could, at their discretion, adopt increased uncertainty buffers (e.g., the level of risk or probability of overfishing, e.g., P^*; Prager et al. 2003; Shertzer et al. 2008; Prager and Shertzer 2010; Methot et al. 2014; sensu Methot 2009) in setting annual catch limits, potential biological removals, etc. For other situations, ecosystem, social, or other indicators may also provide plausible motivations for adding greater precaution. We note that the continuity approach could — and the precautionary approach almost invariably would — lead to reductions in catch under uncertainty and hence tends to only focus on the natural resources and not on the communities that are dependent on them. COVID-19 may prove to be a more uniquely human perturbation than a stress on natural resources, and adopting catch reductions commensurate with the strict precautionary approach coupled with severe economic disruptions could lead to further impacts on fishing communities. Though some short-term economic relief has been provided through the CARES Act (https://www.fisheries.noaa.gov/national/noaa-fisheries-coronavirus-covid-19-update), the impacts of COVID-19 will be multifaceted and long-lasting beyond the analytical considerations noted here. Socioeconomic analysis to explore these COVID-19 impacts will most likely be done in retrospect, but nascent efforts to evaluate them are underway. Hence, we recommend the continuity of advice approach, which unless indicated otherwise, could serve as a default approach that balances resource conservation, human impacts, and the substantial analytical and rule-making burden necessary for formally applying a precautionary approach. The major risk with a continuity default is that one assumes status quo, but if something drastic happens in an ecosystem (e.g., occurrences of marine heat waves, harmful algal blooms, etc.), then assumptions of stationary and basal conditions are incorrect; this is why it will be important to maintain citizen science efforts (see above) to assist with such observations and why we need to be ready to adopt the more formal precautionary approach.

It may be that we simply support Fishery Management Councils, State Marine Fisheries Commissions, Scientific Review Groups, and other management partners in the normal rule-setting process, and especially those that invoke emergency rules for unassessed stocks and (or) maintain current catch and removal levels, aiming to simply postpone our analytical efforts beyond what we can reasonably forecast. However, the items listed above (Table 1) are some of the alternatives we can consider as we scope and scale those emergency decisions, while the assessments to directly support them may be delayed as we await novel data. Some items noted urgently need implementation now (retaining continuity, employing data-poor methods, continuing short-term projections, using management procedures, conducting risk assessments, using indicators), while others can be viewed as being needed as soon as is feasible but also to spark escalation of their more widespread (and needed) adoption (escalate MSE development, early warning signals; Table 1).

Development of advice and debate of scientifically based management options in a limited travel context

There remains the need to gather and analyze data, implement models that use the data, and review the model outputs. There remains the need to evaluate those outputs and translate them into advice. There remains the need to establish the amount of catch or removal and the need to debate the allocations thereof. We are always going to need to have our staff, our partners, and our stakeholders interact. The present COVID-19 situation has likely provided a fundamental and possibly lasting shift in how our activities will be conducted moving forward (e.g., Kramer and Kramer 2020).

For at least the forseeable future, we expect the criteria for travel approval will likely remain stricter than before COVID-19, but not as strict as the essential or mission-critical travel criteria we currently have in place for COVID-19. That is, within NOAA and similar organizations, this essential travel would be travel limited to that necessary to accomplish an immediate, mission-critical, mandated task and when risks relative to human health are mitigated. Besides federal rules, different states, academic institutions, companies, and NGOs all have separate rules for travel that affect the ability to hold meetings. The diversity of such travel rules makes holding meetings a challenge. Collectively, these challenges will reduce the number of in-person meetings, and hence travel, to those activities that can truly only be done in person, causing us to rethink our approach for prioritizing work-related travel. As we all learn more about COVID-19, and as additional mitigation measures are put into place, developing revised criteria for travel will be a useful outcome of the present situation. An intentional evaluation of what has been learned when working and meeting remotely is an effort that could usefully inform future meetings. There still needs to be time and opportunity to meet in person, but perhaps in a more strategic and deliberate manner.

The need to shift to online meetings is now feasible, and such online meetings will likely continue more than they did before COVID-19. The efficacy of these online meetings needs to continue to be evaluated. The ability to shift to this more online approach, and the technological capacity to do so, is rapidly evolving. Most of us have adapted to the many video conferences and meetings now common in the COVID-19 situation, and with a few exceptions these are mostly quite functional (Price 2020). One positive outcome of this more "virtualized" working environment is the opportunity for increased collaborative efforts, as barriers to such efforts have been notably lowered by the present situation. Perhaps any savings in more constrained travel could be partially applied to updating the necessary technology and capacity to expand or improve associated online endeavors. If an online presence continues or if it is expanded, the posture of our IT and related staff needs to continue to be, but even more so, one of access and connection over security, not vice-versa (International Telecommunication Union 2020). Issues of database access and information sharing while maintaining reasonable cybersecurity warrant further attention in this context.

The future of telework, and its possible expanded use, needs to be assessed. NOAA Fisheries entered mandatory telework in March 2020, and much of our work continued. Certainly, the need to stage field or cruise work, to maintain living organisms, and to conduct laboratory work are not conducive to telework. But much of what we do in our mission can be accomplished via telework or work-from-home scenarios. The implications of this proposed expansion are both potentially positive — less commuting, morale boost, more time to focus on work, potentially less facilities and utilities direct costs, fewer distractions, increased productivity — and also potentially negative — loss of serendipitous hallway interactions, lack of accountability, loss of camaraderie, increased compute and IT costs, more distractions. The COVID-19 situation has afforded us essentially with a test. The test has effectively shown that the assumptions and concerns of widespread telework at-scale were largely unfounded and warrant being revisited (Ogrysko 2020; Thornton 2020); that is, our personnel are finding ways to adjust and remain remarkably productive (Smith 2020; Thornton 2020). Although productive and still meeting many facets of our mission, we also do not want to overstate the ability of our personnel to maintain productivity given some of the unique challenges arising from work-from-home scenarios, especially over extended periods of time. Nor do we want to understate the differential impacts resulting from work-from-home scenarios, particularly for personnel with dependents at home, impacted from school closures, etc. A clear review of lessons learned during the ongoing COVID-19 situation would be helpful to better clarify when telework works well and what conditions need to be established for it to be (even more) successful. Any such conditions particularly need to include discussions on computing power, bandwidth, etc., and how those can be maintained and more widely sourced, as well as "empathetic" policies for those with dependents at home. From that, we expect evaluation criteria will evolve and be applied to ascertain the key lessons learned from this de facto teleworking experiment.

There are several considerations regarding travel, telework, and how we all conduct meetings during COVID-19 (Table 1). Some of these recommendations need to be resolved in the short term (e.g., evaluate effectiveness of online meetings, invest in information technology software, evaluate telework effectiveness, etc.), and some need to be started now and continued into the immediate future, and some need to be used to improve or revise our long-term operations (Table 1). The larger, macroeconomic sense is that how we all execute our normal operating protocols of doing business have been disrupted — some maybe irreversibly — due to COVID-19 (Kramer and Kramer 2020; i.e., "Will you ever go back to the office again?"). Using the COVID-19 situation as a rationale to evaluate and revise how we conduct parts of our mission seems not only wise, but appropriate, as we are in the midst of it, and a real-time examination of this information should minimize the global disruptions thereof (Cho 2020; Kramer and Kramer 2020).

A note on organizational excellence

Equal to the LMR-focused aspects of our mission, one of the main priorities for NOAA Fisheries is organizational excellence. What that means is we want NOAA Fisheries to continue to be an organization that is a workplace of choice, both for our personnel and for interested candidates not yet with us; an organization that takes care of its people; and an organization that is constantly trying to improve how it does business. We suspect that most fisheries and marine science organizations have similar aspirations. That involves a range of discussions on topics that are more science support than directly science, but which are mission-critical. The COVID-19 situation may provide an opportunity to revisit some of these issues by necessity.

We note that these organizational considerations are being pondered more deeply in other contexts, but here we briefly highlight some important considerations. For instance, what opportunities does COVID-19 afford in terms of professional development, training, continuing education, mentoring, temporary assignments to expand networks and experience, etc.? Related to work-from-home considerations noted above, COVID-19 is forcing us to consider other facets of our organization: what facilities do we need, should we consider desk-sharing (cf. Sander 2017), do we need to revisit organizational structure to perhaps capture "virtual" centers of excellence, are there efficiencies that have arisen in how we conduct our business that we need to more widely adopt, do we need to change standard operating procedures, etc.? The salient point is that we need to continue to evaluate all of our organizational dynamics and build on outcomes from a series of program reviews (NMFS 2013, 2014*a*, 2014*b*, 2015, 2016*c*, 2017; NOAA Fisheries Office of Science and Technology 2018*b*) to continue to improve how we do business in light of the particular exigencies of the COVID-19 situation.

Ad extremum verbum

We recognize that many of us in fisheries and marine science organizations are simply trying to deal with the day-to-day challenges of the COVID-19 situation — both professionally and personally — and that ultimately, we all need to find ways to mitigate the effects of COVID-19 on our missions. But we also recognize the need to glean information from our responses while in the midst of the current situation to take advantage of any lessons learned that could improve how we conduct our mission moving forward. Ideally, we would like to implement any of the above recommendations (Table 1) after full mitigation of COVID-19, but short of that we wanted to explore possible solutions that minimize the COVID-19 risk while still affording us the ability to conduct the work needed for our mission. What we present in this work represents some "in-the-moment" attempts to deal with the tactical while also thinking strategically. We present these perspectives in part to signal our intentions, in part to learn what others may be doing, and ultimately to foster a discussion on the topic for the discipline. We offer these thoughts not as having solved any and every problem, but as a means to foster ongoing discussions within the wider fisheries and marine science communities so that we do not squander this historic opportunity. If this thought-piece results in even one important next step to advance some much-needed changes in our discipline, we will have succeeded.

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References

Addetia, A., Crawford, K.H.D., Dingens, A., Zhu, H., Roychoudhury, P., Huang, M.-L., et al. 2020. Neutralizing antibodies correlate with protection from SARS-CoV-2 in humans during a fishery vessel outbreak with high attack rate. J. Clin. Microbiol. doi:10.1128/JCM.02107-20.

Ames, R.T., Leaman, B.M., and Ames, K.L. 2007. Evaluation of Video Technology for Monitoring of Multispecies Longline Catches. North Am. J. Fish. Manage. **27**(3): 955–964. doi:10.1577/m06-029.1.

Ault, J.S., Smith, S.G., Richards, B.L., Yau, A.J., Langseth, B., Humphreys, R., et al. 2018. Towards Fishery-independent Biomass Estimation for Hawaiian Deep 7 Bottomfish. NOAA Tech Memo. NMFS-PIFSC-67.

Ballance, L., Srinivasan, M., Henry, A., Angliss, R., Barre, L., Barlow, J., et al. 2017. A strategic plan for conducting large geographic scale, ship-based surveys to support the U.S. Marine Mammal Protection and Endangered Species Acts. NOAA Tech. Memo. NMFS-F/SPO-169.

Bastardie, F., Nielsen, J.R., Ulrich, C., Egekvist, J., and Degel, H. 2010. Detailed mapping of fishing effort and landings by coupling fishing logbooks with satellite-recorded vessel geo-location. Fish. Res. **106**(1): 41–53. doi:10.1016/j.fishres.2010.06.016.

Bennett, N.J., Finkbeiner, E.M., Ban, N.C., Belhabib, D., Jupiter, S.D., Kittinger, J.N., et al. 2020. The COVID-19 Pandemic, Small-Scale Fisheries and Coastal Fishing Communities. Coastal Management, **48**(4): 336–347. doi:10.1080/08920753.2020.1766937.

Berwyn, B. 2020. Q&A: Oceanographers Tell How the Pandemic Crimps Global Ocean and Climate Monitoring [online]. Available from https://insideclimatenews.org/news/24072020/oceanographers-coronavirus-research-science-climate.

Borggaard, D.L., et al. 2019. Atlantic Salmon Scenario Planning Pilot Report. Greater Atlantic Region Policy Series [19-05] [online]. NOAA Fisheries Greater Atlantic Regional Fisheries Office. Available from www.greateratlantic.fisheries.noaa.gov/policyseries.

Bradley, D., Merrifield, M., Miller, K.M., Lomonico, S., Wilson, J.R., and Gleason, M.G. 2019. Opportunities to improve fisheries management through innovative technology and advanced data systems. Fish Fish. **20**(3): 564–583. doi:10.1111/faf.12361.

Carter, D.W., Crosson, S., and Liese, C. 2015. Nowcasting Intraseasonal Recreational Fishing Harvest with Internet Search Volume. PLoS ONE, **10**(9): e0137752. doi:10.1371/journal.pone.0137752. PMID:26348645.

Carruthers, T.R., Punt, A.E., Walters, C.J., MacCall, A., McAllister, M.K., Dick, E.J., and Cope, J. 2014. Evaluating methods for setting catch limits in data-limited fisheries. Fish. Res. **153**: 48–68. doi:10.1016/j.fishres.2013.12.014.

Chrysafi, A., and Kuparinen, A. 2016. Assessing abundance of populations with limited data: Lessons learned from data-poor fisheries stock assessment. Environ. Rev. **24**(1): 25–38. doi:10.1139/er-2015-0044.

Cho, E. 2020. Examining boundaries to understand the impact of COVID-19 on vocational behaviors. J. Vocat. Behav. **119**(2020): 103437. doi:10.1016/j.jvb.2020.103437. PMID:32390657.

CCFA. 2020. Reducing control during the Covid-19 outbreak would open the door to illegal fishing [online]. Coalition for Fair Fisheries Arrangements. Available from https://www.cffacape.org/news-blog/reducing-control-during-the-covid-19-outbreak-would-open-the-door-to-illegal-fishing.

Cope, J.M. 2013. Implementing a statistical catch-at-age model (Stock Synthesis) as a tool for deriving overfishing limits in data-limited situations. Fish. Res. **142**: 3–14. doi:10.1016/j.fishres.2012.03.006.

Cope, J.M., and Punt, A.E. 2009. Length-Based Reference Points for Data-Limited Situations: Applications and Restrictions. Mar. Coast. Fish. **1**(1): 169–186. doi:10.1577/c08-025.1.

Cottrell, R.S., Nash, K.L., Halpern, B.S., Remenyi, T.A., Corney, S.P., Fleming, A., et al. 2019. Food production shocks across land and sea. Nat. Sustain. **2**(2): 130–137. doi:10.1038/s41893-018-0210-1.

Crandall, C.A., Monroe, M., Dutka-Gianelli, J., Fitzgerald, B., and Lorenzen, K. 2018. How to Bait the Hook: Identifying What Motivates Anglers to Participate in a Volunteer Angler Program. Fisheries, **43**(11): 517–526. doi:10.1002/fsh.10156.

Crozier, L.G., McClure, M.M., Beechie, T., Bograd, S.J., Boughton, D.A., Carr, M., et al. 2019. Climate vulnerability assessment for Pacific salmon and steelhead in the California Current Large Marine Ecosystem. PLoS ONE, **14**(7): e0217711. doi:10.1371/journal.pone.0217711. PMID:31339895.

Cury, P.M., Shannon, L.J., Roux, J.P., Daskalov, G.M., Jarre, A., Moloney, C.L., and Pauly, D. 2005. Trophodynamic indicators for an ecosystem approach to fisheries. ICES J. Mar. Sci. **62**(3): 430–442. doi:10.1016/j.icesjms.2004.12.006.

Darcy, G.H., and Matlock, G.C. 1999. Application of the precautionary approach in the national standard guidelines for conservation and

management of fisheries in the United States. ICES J. Mar. Sci. **56**(6): 853–859. doi:10.1006/jmsc.1999.0533.
DePiper, G.S., Gaichas, S.K., Lucey, S.M., Pinto da Silva, P., Anderson, M.R., Breeze, H., et al. 2017. Operationalizing integrated ecosystem assessments within a multidisciplinary team: lessons learned from a worked example. ICES J. Mar. Sci. **74**(8): 2076–2086. doi:10.1093/icesjms/fsx038.
De La Mare, W.K. 1998. Tidier Fisheries management requires a new MOP (management-oriented paradigm). Rev. Fish Biol. Fish. **8**(3): 349–356. doi:10.1023/A:1008819416162.
deValpine, M.G. 2015. Influenza in Bristol Bay, 1919: "The saddest repudiation of a benevolent intention". SAGE Open, **5**(1): 1–8. doi:10.1177/2158244015577418.
Doremus, P. 2020. Statement from National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce: Impacts of COVID-19 Pandemic on U.S. Fisheries before the Committee on Commerce, Science, and Transportation, U.S. Senate. 29 July 2020.
Dorn, M., and Zador, S. 2020. A risk table to address concerns external to stock assessments when developing fisheries harvest recommendations. Ecosystem Health and Sustainability.
Eliasen, S.Q., Papadopoulou, K.-N., Vassilopoulou, V., and Catchpole, T.L. 2014. Socio-economic and institutional incentives influencing fishers' behaviour in relation to fishing practices and discard. ICES J. Mar. Sci. **71**(5): 1298–1307. doi:10.1038/278097a0, doi:10.1093/icesjms/fst120.
Essington, T.E. 2001. The precautionary approach in fisheries management: the devil is in the details. TREE, **16**(3): 121–122. doi:10.1016/S0169-5347(00)02079-6.
Fairclough, D.V., Brown, J.I., Carlish, B.J., Crisafulli, B.M., and Keay, I.S. 2014. Breathing life into fisheries stock assessments with citizen science. Sci. Rep. **4**: 7249. doi:10.1038/srep07249. PMID:25431103.
FAO. 2020*a*. How is COVID-19 affecting the fisheries and aquaculture food systems. Rome. doi:10.4060/ca8637en.
FAO. 2020*b*. The impact of COVID-19 on fisheries and aquaculture — A global assessment from the perspective of regional fishery bodies: Initial assessment. Rome. doi:10.4060/ca9279en.
FAO. 2020*c*. Novel Coronavirus (COVID-19). Q&A: COVID-19 pandemic — impact on fisheries and aquaculture [online]. Available from http://www.fao.org/2019-ncov/q-and-a/impact-on-fisheries-and-aquaculture/en/.
Fay, G., Link, J.S., Large, S., and Gamble, R. 2015. Management performance of Ecol. Indic. in the Georges Bank finfishery. ICES J. Mar Sci. **72**(5): 1285–1296. doi:10.1093/icesjms/fsu214.
Fay, G., Large, S.I., Link, J.S., and Gamble, R.J. 2013. Testing systemic fishing responses with ecosystem indicators. Ecol. Modell. **265**: 45–55. doi:10.1016/j.ecolmodel.2013.05.016.
Francis, T.B., Levin, P.S., Punt, A.E., Kaplan, I.C., Varney, A., and Norman, K. 2018. Linking knowledge to action in ocean ecosystem management: The Ocean Modeling Forum. Elem. Sci. Anth. **6**(1): 83. doi:10.1525/elementa.338.
Fulton, E.A., Punt, A.E., Dichmont, C.M., Harvey, C.J., and Gorton, R. 2019. Ecosystems say good management pays off. Fish Fish. **20**(1): 66–96. doi:10.1111/faf.12324.
Gaichas, S.K., Link, J.S., and Hare, J.A. 2014. A risk-based approach to evaluating northeast US fish community vulnerability to climate change. ICES J. Mar. Sci. **71**(8): 2323–2342. doi:10.1093/icesjms/fsu048.
Gaichas, S.K., DePiper, G.S., Seagraves, R.J., Muffley, B.W., Sabo, M.G., Colburn, L.L., and Loftus, A.J. 2018. Implementing Ecosystem Approaches to Fishery Management: Risk Assessment in the US Mid-Atlantic. Front. Mar. Sci. **5**: 442. doi:10.3389/fmars.2018.00442.
Gephart, J.A., Rovenskaya, E., Dieckmann, U., Pace, M.L., and Brännström, Å. 2016. Vulnerability to shocks in the global seafood trade network. Environ. Res. Lett. **11**(3): 035008. doi:10.1088/1748-9326/11/3/035008.
Gephart, J.A., Deutsch, L., Pace, M.L., Troell, M., and Seekell, D.A. 2017. Shocks to fish production: Identification, trends, and consequences. Global Environ. Change. **42**: 24–32. doi:10.1016/j.gloenvcha.2016.11.003.
Geromont, H.F., and Butterworth, D.S. 2015. Generic management procedures for data-poor fisheries: forecasting with few data. ICES J. Mar. Sci. **72**(1): 251–261. doi:10.1038/278097a0.
Gerritsen, H., and Lordan, C. 2011. Integrating vessel monitoring systems (VMS) data with daily catch data from logbooks to explore the spatial distribution of catch and effort at high resolution. ICES J. Mar. Sci. **68**(1): 245–252. doi:10.1093/icesjms/fsq137.
Gibson, J., and Wozniak, E. 2020. International Fisheries Managers' Pandemic Response Highlights Need to Expand Electronic Monitoring [online]. The Pew Charitable Trusts. Available from https://www.pewtrusts.org/en/research-and-analysis/articles/2020/05/01/international-fisheries-managers-pandemic-response-highlights-need-to-expand-electronic-monitoring.
Graber-Stiehl, I. 2020. Research cruises gingerly resume. Science, **369**(6502): 358. doi:10.1126/science.369.6502.358. PMID:32703856.
Hare, J.A., Morrison, W.E., Nelson, M.W., Stachura, M.M., Teeters, E.J., Griffis, R.B., et al. 2016. A vulnerability assessment of fish and invertebrates to climate change on the northeast U.S. continental shelf. PLoS ONE, **11**(2): e0146756. doi:10.1371/journal.pone.0146756.
Harris, J.M., Nelson, J.A., Rieucau, G., and Broussard, W.P. 2019. Use of Drones in Fishery Science. Trans. Am. Fish. Soc. **148**(4): 687–697. doi:10.1002/tafs.10168.
Heslop, A.E., Fischer, A., Tanhua, T., Legler, D., and Belbeoch, M. 2020. Covid-19's impact on the ocean observing system and our ability to forecast weather and predict climate change. Global Ocean Observing System.
Heupel, M.R., and Webber, D.M. 2012. Trends in acoustic tracking: Where are the fish going and how will we follow them? Am. Fish. Soc. Symp. **76**: 219–231.
Hilborn, R., Maguire, J.-J., Parma, A.M., and Rosenberg, A.A. 2001. The Precautionary Approach and risk management: can they increase the probability of successes in fishery management? Can. J. Fish. Aquat. Sci. **58**(1): 99–107. doi:10.1139/f00-225.
Hold, N., Murray, L.G., Pantin, J.R., Haig, J.A., Hinz, H., and Kaiser, M.J. 2015. Video capture of crustacean fisheries data as an alternative to on-board observers. ICES J. Mar. Sci. **72**(6): 1811–1821. doi:10.1093/icesjms/fsv030.
Huynh, Q.C., Hordyk, A.R., Forrest, R.E., Porch, C.E., Anderson, S.C., and Carruthers, T.R. 2020. The interim management procedure approach for assessed stocks: Responsive management advice and lower assessment frequency. Fish Fish. **21**(3): 663–679. doi:10.1111/faf.12453.
ICES. 2020. Workshop on Unavoidable Survey Effort Reduction, Seattle, WA [online]. Available from https://www.fisheries.noaa.gov/event/2020-international-council-exploration-sea-ices-workshop-announcement-unavoidable-survey.
IEA. 2019. Ecosystem Status Reports: A synthesis of the status and trends of an ecosystem [online]. Available from https://www.integratedecosystemassessment.noaa.gov/national/Ecosystem-Status-Reports.
International Telecommunication Union. 2020. Pandemic in the Internet Age: communications industry responses [online]. Geneva. Available from https://reg4covid.itu.int/wp-content/uploads/2020/06/ITU_COVID-19_and_Telecom-ICT.pdf.
Jiorle, R.P., Ahrens, R.N.M., and Allen, M.S. 2016. Assessing the Utility of a Smartphone App for Recreational Fishery Catch Data. Fisheries, **41**(12): 758–766. doi:10.1080/03632415.2016.1249709.
Kaplan, I.C., and Leonard, J. 2012. From krill to convenience stores: Forecasting the economic and ecological effects of fisheries management on the US West Coast. Mar. Pol. **36**(5): 947–954. doi:10.1016/j.marpol.2012.02.005.
Kearns, M. 2020. COVID-19 prompts NOAA to extend fisheries observer waiver for the US Greater Atlantic region [online]. SeafoodSource. Available from https://www.seafoodsource.com/news/supply-trade/covid-19-prompts-noaa-to-extend-fisheries-observer-waiver-for-the-us-greater-atlantic-region.
Kemp, P.S., Froese, R., and Pauly, D. 2020. COVID-19 provides an opportunity to advance a sustainable UK fisheries policy in a post-Brexit brave new world. Mar. Pol. **120**(2020): 104114. doi:10.1016/j.marpol.2020.104114.
Kindt-Larsen, L., Kirkegaard, E., and Dalskov, J. 2011. Fully documented fishery: A tool to support a catch quota management system. ICES J. Mar. Sci. **68**(8): 1606–1610. doi:10.1093/icesjms/fsr065.
Kramer, A., and Kramer, K.Z. 2020. The potential impact of the Covid-19 pandemic on occupational status, work from home, and occupational mobility. J. Vocat. Behav. **119**(2020): 103442. doi:10.1016/j.jvb.2020.103442. PMID:32390661.
Large, S.I., Fay, G., Friedland, K.D., and Link, J.S. 2015. Quantifying patterns of change in marine ecosystem response to multiple pressures. PLoS ONE, **10**(3): e0119922. doi:10.1371/journal.pone.0119922. PMID:25781166.
Lederhouse, T., and Link, J.S. 2016. A proposal for indicators of fishery habitat conservation success. Coastal Manag. J. **44**(3): 209–222. doi:10.1080/08920753.2016.1163176.
Link, J.S. 2005. Translation of Ecosystem Indicators into Decision Criteria. ICES J. Mar. Sci. **62**(3): 569–576. doi:10.1016/j.icesjms.2004.12.015.
Link, J.S., Brodziak, J.K.T., Edwards, S.F., Overholtz, W.J., Mountain, D., Jossi, J.W., et al. 2002. Marine Ecosystem Assessment in a Fisheries Management Context. Can. J. Fish. Aquat. Sci. **59**(9): 1429–1440. doi:10.1139/f02-115.
Link, J.S., Griffis, R.B., and Busch, D.S. 2015. NOAA Fisheries Climate Science Strategy. NOAA Tech. Memo. NMFS-F/SPO-155.
Libralato, S., Pranovi, F., Zucchetta, M., Anelli Monti, M., and Link, J.S. 2019. Global Thresholds in properties emerging from Cumulative Curves of Marine Ecosystems. Ecol. Indic. **103**: 554–562. doi:10.1016/j.ecolind.2019.03.053.
Link, J.S., and Watson, R.A. 2019. Global ecosystem overfishing: Clear delineation within real limits to production. Sci. Adv. **5**(6): eaav0474. doi:10.1126/sciadv.aav0474.
Lynch, P.D., Methot, R.D., and Link, J.S. 2018. TM NMFS-F/SPO-183: Implementing a Next Generation Stock Assessment Enterprise. An Update to the NOAA Fisheries Stock Assessment Improvement Plan. NOAA Tech. Memo. NMFS F/SPO. doi:10.7755/TMSPO.183
Mangi, S.C., Dolder, P.J., Catchpole, T.L., Rodmell, D., and de Rozarieux, N. 2015. Approaches to fully documented fisheries: Practical issues and stakeholder perceptions. Fish Fish. **16**(3): 426–452. doi:10.1111/faf.12065.
McDonald, G., Harford, B., Arrivillaga, A., Babcock, E.A., Carcamo, R., Foley, J., et al. 2017. An indicator-based adaptive management framework and its development for data-limited fisheries in Belize. Mar. Pol. **76**: 28–37. doi:10.1016/j.marpol.2016.11.027.
McKinley, D.C., Miller-Rushing, A.J., Ballard, H.L., Bonney, R., Brown, H., Cook-Patton, S.C., et al. 2017. Citizen science can improve conservation science, natural resource management, and environmental protection. Biol. Conserv. **208**: 15–28. doi:10.1016/j.biocon.2016.05.015.
McLaughlin, K.D. 2008. Mitigating Impacts of Natural Hazards on Fishery Ecosystems. AFS Symposium 64.
Methot, R.D. 2009. Stock Assessment: Operational Models in Support of Fisheries Management. In The Future of Fisheries Science in North America. *Edited by* R.J. Beamish and R.J. Rothschild. Springer. pp. 137–165. doi:10.1007/978-1-4020-9210-7.

Methot, J.R., and Richard, D. 2015. Prioritizing fish stock assessments. U.S. Dep. Commer. NOAA Tech. Memo. NMFS-F/SPO-152.

Methot, R.D., Tromble, G.R., Lambert, D.M., and Greene, K.E. 2014. Implementing a science-based system for preventing overfishing and guiding sustainable fisheries in the United States. ICES J. Mar. Sci. **71**(2): 183–194. doi:10.1093/icesjms/fst119.

Meuel, T., Prado, G., Seychelles, F., Bessafi, M., and Kellay, H. 2012. Hurricane track forecast cones from fluctuations. Sci. Rep. **2**: 446. doi:10.1038/srep00446. PMID:22701776.

Moustahfid, H., Micheals, W., Alger, B., Gangopadhyay, A., and Brehmer, P. 2020. Advances in Fish. Sci. Through Emerging Observing Technologies. Environmental Coastal & Offshore, **2020**(Jul/Aug): 34–37.

NMFS. 2013. National Response to the FY 2013 Reviews of NOAA Fisheries' Stock Assessment Data Collection and Management Programs. National Marine Fisheries Service.

NMFS. 2014*a*. NOAA Fisheries Stock Assessments in 2014: Program Review and Plans for Advancements and Improvement. National Marine Fisheries Service.

NMFS. 2014*b*. Program Reviews: Improving Our Science. National Marine Fisheries Service.

NMFS. 2015. National Response to the FY 2015 Reviews of NOAA Fisheries' Protected Species Science Programs. National Marine Fisheries Service.

NMFS. 2016*a*. Ecosystem-based fisheries management policy. National Marine Fisheries Service Policy Directive 01-120. National Marine Fisheries Service.

NMFS. 2016*b*. Ecosystem-based fisheries management policy. National Marine Fisheries Service Policy Directive 01-120-01. National Marine Fisheries Service.

NMFS. 2016*c*. National Response to the FY 2016 Reviews of NOAA Fisheries' Ecosystem-Related Science Programs. National Marine Fisheries Service.

NMFS. 2017. Economics & Human Dimensions Program Review. National Marine Fisheries Service.

NMFS. 2019. NOAA Fisheries Strategic Plan 2019–2022. National Marine Fisheries Service, Silver Spring, Md.

NMFS. 2020*a*. NOAA Fisheries Adapts to Changing Circumstances; Different Requirements Call for Different Approaches to Observers and Monitors [online]. National Marine Fisheries Service, NOAA. Available from https://www.fisheries.noaa.gov/leadership-message/noaa-fisheries-adapts-changing-circumstances-different-requirements-call-different.

NMFS. 2020*b*. NOAA Fisheries Priorities and Annual Guidance. National Marine Fisheries Service.

NMFS. 2020*c*. Stock Assessment Model Descriptions [online]. National Marine Fisheries Service, NOAA. Available from https://www.fisheries.noaa.gov/insight/stock-assessment-model-descriptions.

NMFS. 2020*d*. Temporary Waivers on Northeast Observers, Monitors through August 13, Resuming Coverage August 14 [online]. National Marine Fisheries Service, NOAA. Available from https://www.fisheries.noaa.gov/bulletin/temporary-0waivers-northeast-observers-monitors-through-august-13-resuming-coverage.

NMFS. 2020*e*. Glider Piloting with Jen: Deploying the Gliders [online]. National Marine Fisheries Service, NOAA. Available from https://www.fisheries.noaa.gov/science-blog/glider-piloting-jen-deploying-gliders.

NMFS 2020*f*. Cooperative Research Program. National Marine Fisheries Service. Available from https://www.fisheries.noaa.gov/grant/cooperative-research-program.

NOAA. 2009. Scenarios for 2035: long-term trends, challenges and uncertainties facing NOAA. Working Document of NOAA, Planning.

NOAA. 2016. The NOAA, Fleet Plan: Building NOAA's 21st Century Fleet.

NOAA. 2020. Science and Technology Focus Areas. Available from https://nrc.noaa.gov/NOAA-Science-Technology-Focus-Areas.

NOAA Fisheries. 2020*a*. NOAA Fisheries Coronavirus (COVID-19) Update. Available from https://www.fisheries.noaa.gov/national/noaa-fisheries-coronavirus-covid-19-update.

NOAA Fisheries. 2020*b*. NOAA Fisheries will Cancel Five Alaska Research Surveys for 2020. Available from https://www.fisheries.noaa.gov/media-release/noaa-fisheries-will-cancel-five-alaska-research-surveys-2020.

NOAA Fisheries. 2020*c*. NOAA Fisheries Cancels Three Research Surveys. Available from https://content.govdelivery.com/accounts/USNOAAFISHERIES/bulletins/294acb5.

NOAA Fisheries. 2020*d*. Fish Stock Assessment Report. Available from https://www.fisheries.noaa.gov/national/population-assessments/fish-stock-assessment-report#scientific-surveys.

NOAA Fisheries. 2020*e*. NOAA Fisheries Issues Emergency Action to Waive Observer Coverage on a Case-by-Case Basis. Available from https://www.fisheries.noaa.gov/action/noaa-fisheries-issues-emergency-action-waive-observer-coverage-case-case-basis.

NOAA Fisheries Office of Science and Technology. 2018*a*. Implementing Electronic Reporting: The MRIP Action Plan.

NOAA Fisheries Office of Science and Technology. 2018*b*. NOAA Fisheries Science Program Review. Available from https://www.fisheries.noaa.gov/national/about-us/noaa-fisheries-science-program-review.

NOAA Fisheries Office of Science and Technology. 2019. Climate Vulnerability Assessments. Available fromhttps://www.fisheries.noaa.gov/national/climate/climate-vulnerability-assessments.

NOAA Fisheries Office of Science and Technology. 2020. Electronic Reporting At-a-Glance. Available fromhttps://www.fisheries.noaa.gov/recreational-fishing-data/electronic-reporting-glance.

NOAA Science Advisory Board. 2018. NOAA Science Advisory Board Report: Potential for Citizen Science in Support of Data Needs for Ecosystem-Based Science. Silver Spring, Md.

NRC. 1998. Improving Fish Stock Assessments. National Research Council. The National Academies Press. doi:10.17226/5951.

NRC. 2006. Completing the Forecast. National Research Council. The National Academies Press.

NRC. 2011. Critical infrastructure for ocean research and societal needs in 2030. National Research Council. doi:10.17226/13081.

Niall, P., Johnson, S., and Mueller, J. 2002. Updating the accounts: Global mortality of the 1918-1920 "Spanish" influenza pandemic. Bull. History of Medicine. **76**: 105–115.

Ogrysko, N. 2020. Feds are enjoying full-time telework but doubt agencies will embrace it later. Federal News Network. Available from https://federalnewsnetwork.com/mike-causey-federal-report/2020/05/feds-are-enjoying-full-time-telework-but-doubt-agencies-will-embrace-it-later/.

Patrick, W.P., Spencer, O., Ormseth, J., Cope, J., Field, D., Kobayashi., et al. 2009. Use of productivity and susceptibility indices to determine the vulnerability of a stock, with example applications to six U.S. fisheries. NOAA Tech. Memo. NMFS-F/SPO-101.

Peters, R., Marshak, A.R., Brady, M.M., Brown, S.K., Osgood, K., Greene, C., et al. 2018. Habitat Science is a Fundamental in an Ecosystem-Based Fisheries Management Framework: An Update to the Marine Fisheries Habitat Assessment Improvement Plan. NOAA Tech. Memo. NMFS. F/SPO 181.

Peterson, G.D., Cumming, G.S., and Carpenter, S.R. 2003. Scenario planning: a tool for conservation in an uncertain world. Conserv. Biol. **17**(2): 358–366. doi:10.1046/j.1523-1739.2003.01491.x.

Pitcher, T.J. 1999. RAPFISH, a rapid appraisal technique for fisheries, and its application to the Code of Conduct for Responsible Fisheries. FAO Fisheries Circular. **47**(947). FAO, Rome.

Pitcher, T.J., and Preikshot, D. 2001. RAPFISH: a rapid appraisal technique to evaluate the sustainability status of fisheries. Fish. Res. **49**(3): 255–270. doi:10.1016/S0165-7836(00)00205-8.

Potts, T. 2006. A framework for the analysis of sustainability indicator systems in fisheries. Ocean and Coastal Management. **49**(5-6): 259–280. doi:10.1016/j.ocecoaman.2006.03.008.

Prager, M.H., Porch, C.E., Shertzer, K.W., and Caddy, J.F. 2003. Targets and Limits for Management of Fisheries: A Simple Probability-Based Approach. North Am. J. Fish. Manage. **23**(2): 349–361. doi:10.1577/1548-8675(2003)023<0349:TALFMO>2.0.CO;2.

Prager, M.H., and Shertzer, K.W. 2010. Deriving Acceptable Biological Catch from the Overfishing Limit: Implications for Assessment Models. North Am. J. Fish. Manage. **30**(1): 289–294. doi:10.1577/M09-105.1.

Price, M. 2020. Scientists discover upsides of virtual meetings. Science, **368** (6490): 457–458. doi:10.1126/science.368.6490.457. PMID:32355009.

Probst, W.N., Kloppmann, M., and Kraus, G. 2013. Indicator-based status assessment of commercial fish species in the North Sea according to the EU Marine Strategy Framework Directive (MSFD). ICES J. Mar. Sci. **70**(3): 694–706. doi:10.1093/icesjms/fst010.

Punt, A.E. 2008. The FAO Precautionary Approach After Almost 10 Years: Have we Progressed Towards Implementing Simulation-Tested Feedback-Control Management Systems for Fisheries Management? Nat. Res. Model. **19**(4): 441–464. doi:10.1111/j.1939-7445.2006.tb00189.x.

Punt, A.E., Butterworth, D.S., de Moor, C.L., De Oliveira, J.A.A., and Haddon, M. 2016. Management strategy evaluation: Best practices. Fish Fish. **17**(2): 303–334. doi:10.1111/faf.12104.

Punt, A.E., Dunn, A., Elvarsson, B.Þ., Hampton, J., Hoyle, S.D., Maunder, M.N., et al. 2020. Essential features of the next-generation integrated fisheries stock assessment package: A perspective. Fish. Res. **229**: 105617. doi:10.1016/j.fishres.2020.105617.

Reid, A.H., Taubenberger, J.K., and Fanning, T.G. 2001. The 1918 Spanish influenza: Integrating history and biology. Microbes Infect. **3**(1): 81–87. doi:10.1016/S1286-4579(00)01351-4.

Reum, J.C.P., McDonald, P.S., Long, W.C., Holsman, K.K., Divine, L., Armstrong, D., and Armstrong, J. 2020. Rapid assessment of management options for promoting stock rebuilding in data-poor species under climate change. Conserv. Biol. . **34**(3): 611–621. doi:10.1111/cobi.13427. PMID:31663172.

Rice, J. C. 2009. A generalization of the three-stage model for advice using the precautionary approach in fisheries, to apply broadly to ecosystem properties and pressures. ICES J. Mar. Sci. **66**(3): 433–444. doi:10.1093/icesjms/fsp021.

Rosenberg, A.A. 2002. The Precautionary Approach in Application from a Manager's Perspective. Bull. Mar. Sci. **70**: 577–588.

Samhouri, J.F., Levin, P.S., and Ainsworth, C.H. 2010. Identifying Thresholds for Ecosystem-Based Management. PLoS ONE, **5**(1): e8907. doi:10.1371/journal.pone.0008907. PMID:20126647.

Sander, L. 2017. The research on hot-desking and activity-based work isn't so positive. The Conversation. Available from https://theconversation.com/the-research-on-hot-desking-and-activity-based-work-isnt-so-positive-75612.

Scheld, A.M., and Anderson, C.M. 2014. Market effects of catch share management: the case of New England multispecies groundfish. ICES J. Mar. Sci. **71**(7): 1835–1845. doi:10.1038/278097a0, doi:10.1093/icesjms/fsu001.

Schwartz, P. 1996. The art of the long view: planning for the future in an uncertain world. Currency Doubleday.

SFP. 2020. Walmart, Major Retailers Call for Governments to Ensure Sustainably Produced Tuna during COVID-19 [online]. Sustainable Fisheries Partnership. Available from http://sustainablefish.org/News/Walmart-Major-Retailers-Call-for-Governments-to-Ensure-Sustainably-Produced-Tuna-during-COVID-19.

Shertzer, K.W., and Williams, E.W. 2008. Fish assemblages and indicator species: reef fishes off the southeastern United States. Fish. Bull. **106**(3): 257–269.

Shertzer, K.W., Prager, M.H., and Williams, E.H. 2008. A probability-based approach to setting annual catch levels. Fish. Bull. **106**(3): 225–232.

Shin, Y.-J., Bundy, A., Shannon, L.J., Simier, M., Coll, M., Fulton, E.A., et al. 2010. Can simple be useful and reliable? Using ecological indicators for representing and comparing the states of marine ecosystems. ICES J. Mar. Sci. **67**(4): 717–731. doi:10.1093/icesjms/fsp287.

Slater, W.L., DePiper, G., Gove, J.M., Harvey, C.J., Hazen, E.L., Lucey, S.M., et al. 2017. Opportunities and Future Directions to Advance NOAA Fisheries Ecosystem Status Reports (ESRs): Report of the National ESR Workshop NOAA Technical Memorandum NMFS-F/SPO-174. 74 Challenges.

Smith, A.D.M. 1994. Management Strategy Evaluation — The Light on the Hill. *In* Population Dynamics for Fisheries Management: Australian Society for Fish Biology Workshop Proceedings, Perth 24 (25 August 1993). *Edited by* D.A. Hancock. pp. 249–253. Australian Society for Fish Biology.

Smith, J. 2020. NOAA's Cloud Systems Help Manage Telework Capabilities. MeriTalk [online]. Available from https://www.meritalk.com/articles/noaas-cloud-systems-help-manage-telework-capabilities/.

Smyth, T.J., Tilstone, G.H., and Groom, S.B. 2005. Integration of radiative transfer into satellite models of ocean primary production. J. Geophys. Res. C: Oceans. **110**(C10): 1–11. doi:10.1029/2004JC002784.

Smythe, T.C., and Thompson, R. 2015. Conceptualizing Coastal Ecosystem-Based Management: A Mental Models Approach. Soc. Nat. Res. **28**(1): 38–56. doi:10.1080/08941920.2014.933921.

Spencer, P.D., Hollowed, A.B., Sigler, M.F., Hermann, A.J., and Nelson, M.W. 2019. Trait-based climate vulnerability assessments in data-rich systems: an application to eastern Bering Sea fish and invertebrate stocks. Glob. Chang. Biol. **25**(11): 3954–3971. doi:10.1111/gcb.14763. PMID:31531923.

Torres, L.G., Nieukirk, S.L., Lemos, L., and Chandler, T.E. 2018. Drone up! Quantifying whale behavior from a new perspective improves observational capacity. Front. Marine Sci. **5**: 1–14. doi:10.3389/fmars.2018.00319.

Townsend, H. M., Harvey, C., Aydin, K.Y., Gamble, R., Grüss, A., Levin, P.S., et al. 2014. Report of the 3rd National Ecosystem Modeling Workshop (NEMoW 3): Mingling Models for Marine Resource Management – Multiple Model Inference. U.S. Dept. of Commerce, NOAA Tech. Memo. NMFS. F/SPO 149.

The Maritime Executive. 2020*a*. NOAA Cancels Five Large-Scale Fishery Surveys Due to COVID-19. The Maritime Executive. Available from https://www.maritime-executive.com/article/noaa-cancels-five-large-scale-fishery-surveys-due-to-covid-19.

The Maritime Executive. 2020*b*. NOAA Fisheries Cancels Three More Surveys Due to COVID-19 Risk. The Maritime Executive. Available from https://www.maritime-executive.com/article/noaa-fisheries-cancels-three-more-surveys-due-to-covid-19-risk.

Thornton, D. 2020. GAO finds employee productivity is increasing from home. Federal News Network. Available from https://federalnewsnetwork.com/workforce/2020/06/gao-finds-employees-productivity-increasing-from-home/.

Van Helmond, A.T.M., Mortensen, L.O., Plet-Hansen, K.S., Ulrich, C., Needle, C.L., Oesterwind, D., et al. 2020. Electronic monitoring in fisheries: Lessons from global experiences and future opportunities. Fish Fish. **21**(1): 162–189. doi:10.1111/faf.12425.

Van Parijs, S.M., Clark, C.W., Sousa-Lima, R.S., Parks, S.E., Rankin, S., Risch, D., and Van Opzeeland, I.C. 2009. Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales. Mar. Ecol. Prog. Ser. **395**: 21–36. doi:10.3354/meps08123.

Venturelli, P.A., Hyder, K., and Skov, C. 2017. Angler apps as a source of recreational fisheries data: opportunities, challenges and proposed standards. Fish Fish. **18**(3): 578–595. doi:10.1111/faf.12189.

Viglione, G. 2020. A year without conferences? How the coronavirus pandemic could change research. Nature, **579**(7799): 327–328. doi:10.1038/d41586-020-00786-y. PMID:32184489.

Watson, J.T., Haynie, A.C., Sullivan, P.J., Perruso, L., O'Farrell, S., Sanchirico, J.N., and Mueter, F.J. 2018. Vessel monitoring systems (VMS) reveal an increase in fishing efficiency following regulatory changes in a demersal longline fishery. Fish. Res. **207**: 85–94. doi:10.1016/j.fishres.2018.06.006.

Watson, R.A. 2017. A database of global marine commercial, small-scale, illegal and unreported fisheries catch 1950–2014. Sci. Data. **4**: 170039. doi:10.1038/sdata.2017.39. PMID:28398351.

Watson, R.A., Cheung, W.W.L., Anticamara, J.A., Sumaila, R.U., Zeller, D., and Pauly, D. 2013. Global marine yield halved as fishing intensity redoubles. Fish Fish. **14**(4): 493–503. doi:10.1111/j.1467-2979.2012.00483.x.

Witt, M.J., and Godley, B.J. 2007. A Step Towards Seascape Scale Conservation: Using Vessel Monitoring Systems (VMS) to Map Fishing Activity. PLoS One, **2**(10): e1111. doi:10.1371/journal.pone.0001111. PMID:17971874.